# Planetary Protection for Mars 2020

Catharine A. Conley,
NASA Planetary Protection Officer

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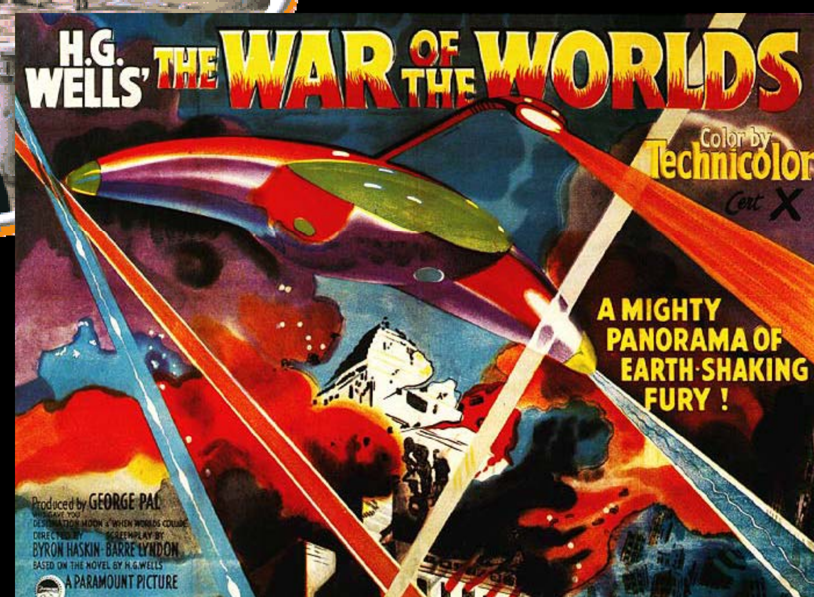
# In a Nutshell...

**H.G. Wells**
**1898**


**Orson Welles**
**1938**

**And scattered about... were the Martians–dead! –slain by the putrefactive and disease bacteria against which their systems were unprepared; slain as the red weed was being slain; slain, after all man's devices had failed, by the humblest things that God, in his wisdom, has put upon this earth.**

**...By virtue of this natural selection of our kind we have developed resisting power; to no germs do we succumb without a struggle...**



# What are the origins, distribution, and future of life in the universe?

It’s trivial to find life, if we bring it with us...

# Early Concerns: Protecting Science during Space Exploration



27 June 1958, Volume 127, Number 3313

SCIENCE

## Moondust

The study of this covering layer by space vehicles may offer clues to the biochemical origin of life.

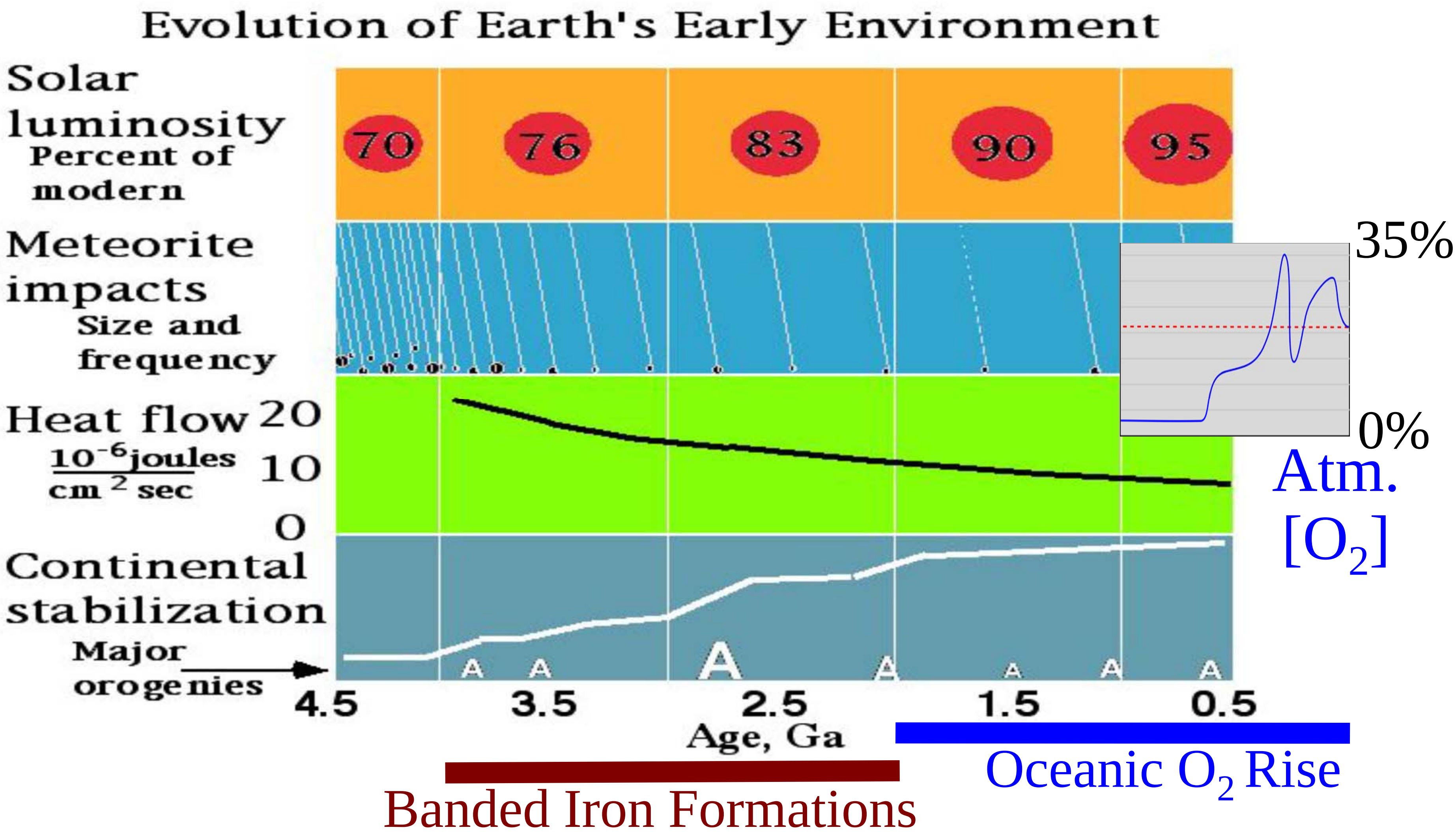
Joshua Lederberg and Dean B. Cowie

tions are very small, they are perhaps large enough to initiate the condensation. If this point is granted, it would then be necessary to examine the capture of a second atom of hydrogen or of carbon by the CH molecule. Because of the abundance of hydrogen, the first is more probable but the calculation of the probability of formation of the $CH_2$ molecule is very difficult. It is possible that some more hydrogen atoms attach themselves to the $CH_2$ molecule ($CH_2$ $CH_3$ $CH_4$ ?) but before long it is mainly atoms of much larger mass (C, N, O, . . .) which are captured because the large molecule

"…we urgently need to give some thought to the conservative measures needed to protect future scientific objectives on the moon and the planets"

# Life Affects the Evolution of Planets

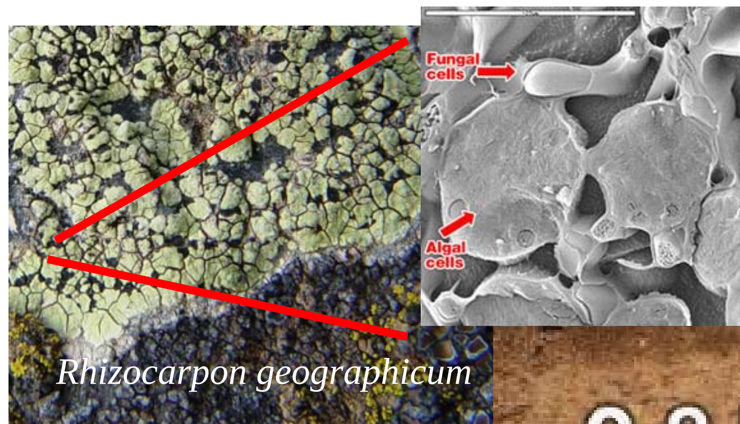




# Microbes are Everywhere on Earth



Most organisms live in fairly complex communities, in which members share resources and improve community survival


Lichen survives space exposure

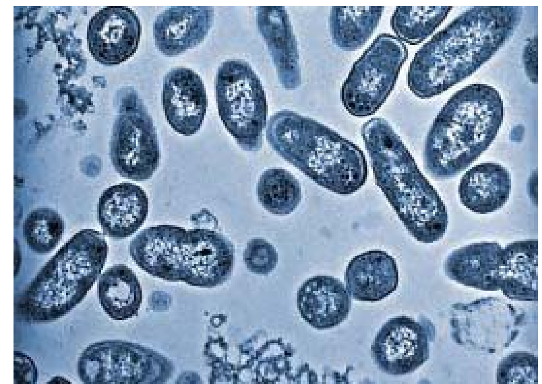

Some communities are made up of small numbers of species: frequently found in more 'extreme' environments

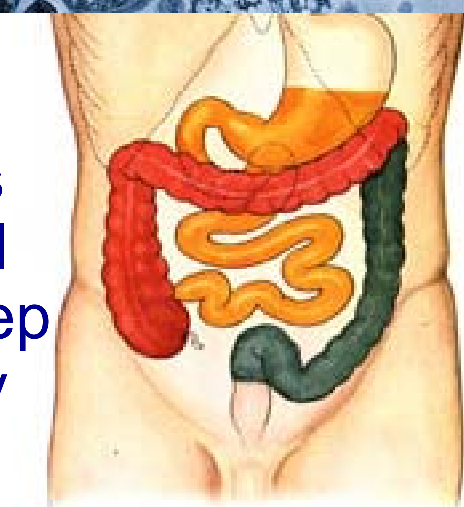
# Introduced Organisms Can Have Ecological Impacts

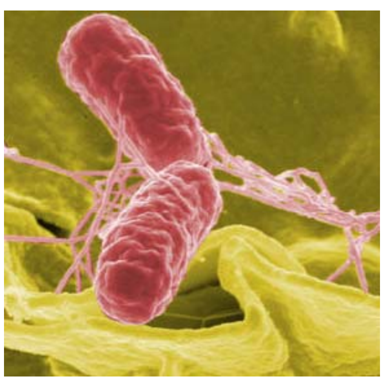


Most stable communities are resistant to invasion by novel species

*Salmonella typhimurium* express more virulence genes after cultured growth in space







However, sometimes organisms with novel capabilities can sweep through a community

# Life on Earth Keeps Spreading



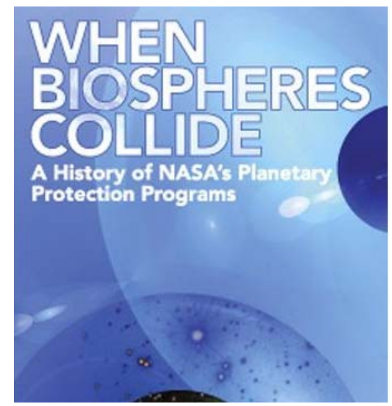
- Before *Deinococcus radiodurans,* we thought we knew how much radiation organisms could tolerate
- Before *Desulforudis audaxviator* (and their nematode predators), we thought we knew where organisms could live
- Organisms making do in 58 Million year old subsea sediments seem to wait around for a rather long time....
- What is the actual range (and duration) of conditions under which Earth Life can grow? Can tolerate? Can survive?
- Given that we know we keep learning more about life on Earth, how do we ensure that other planets are protected?

How do we compensate for what we *don't* know?

# Over 50 Years of International Effort



- 1956, Rome: International Astronautical Foundation meets to discuss lunar and planetary contamination
- Feb. 1958: International Council for Science (ICSU) forms committee on Contamination by ExtraTerrestrial EXploration
- June 1958: NAS establishes the SSB
- July 1958: Formation of UN-COPUOS
- Oct. 1958: Establishment of NASA
- Oct. 1958: Formation of COSPAR by ICSU
- 1959-1962: Publication of guidelines for preventing forward and backward contamination: US, USSR, COSPAR
- 1963: NASA acquires the first 'Planetary Quarantine Officer' – on loan from the Public Health Service



# Current International Framework



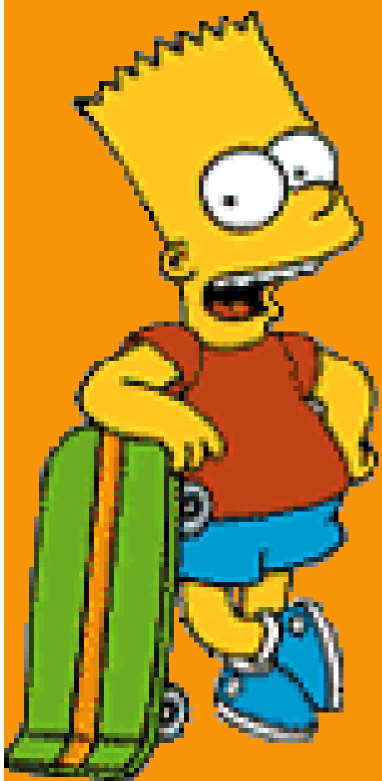
- The Outer Space Treaty of 1967
  - Proposed to the UN in 1966; Signed in January 1967
  - Ratified by the USSR and US Senate by May 1967
  - Article IX of the Treaty states that:

  "...parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose..."

- The Committee on Space Research of the International Council for Science maintains an international consensus policy on planetary protection
  - COSPAR policy represents an international scientific consensus, based on advice from national scientific members, including the US Space Studies Board
  - COSPAR is consultative with the UN (through UN COPUOS and the Office of Outer Space Affairs) on measures to avoid contamination and protect the Earth
  - NASA and ESA policies specify that international robotic missions with agency participation must follow COSPAR policy, as a consensus basis for requirements

# The Basic Rationale for Planetary Protection Precautions

(as written by Bart Simpson, Dec. 17, 2000, "Skinner's Sense of Snow")



**Science class should not end in tragedy....**
**Science class should not end in tragedy....**
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**Science class should not end in tragedy....**
**Science class should not**

# Mission Constraints in NASA Policy



- Depend on the nature of the mission and on the target planet
- Assignment of categories for each specific mission/body is to take into account current scientific knowledge based on recommendations from scientific advisory groups
- Examples of specific measures include:
  - Constraints on spacecraft operating procedures
  - Spacecraft organic inventory and restrictions
  - Reduction of spacecraft biological contamination
  - Restrictions on the handling of returned samples
  - Documentation of spacecraft trajectories and spacecraft material archiving

W. Peet, 1967

# 2020 Science Definition Team Goals



## From the Executive Summary of the 2020 SDT report:

Key features of the integrated science mission concept include:

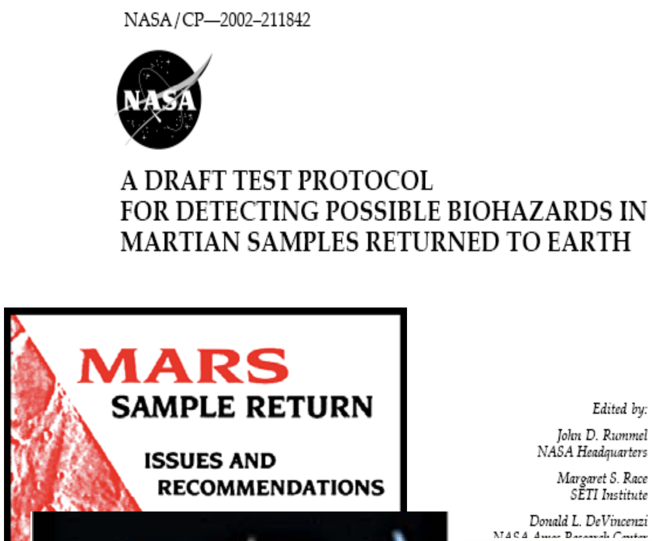
- Broad and rigorous *in situ* science, including seeking the signs of life
- Acquiring a diverse set of samples intended to address a range of Mars science questions and storing them in a cache for potential return to Earth at a later time
- Improved landing technology to allow unprecedented access to scientifically compelling geological sites
- Collection of critical data needed to plan for eventual human missions to the martian surface
- Maximizing engineering heritage from NASA's successful MSL mission to constrain costs

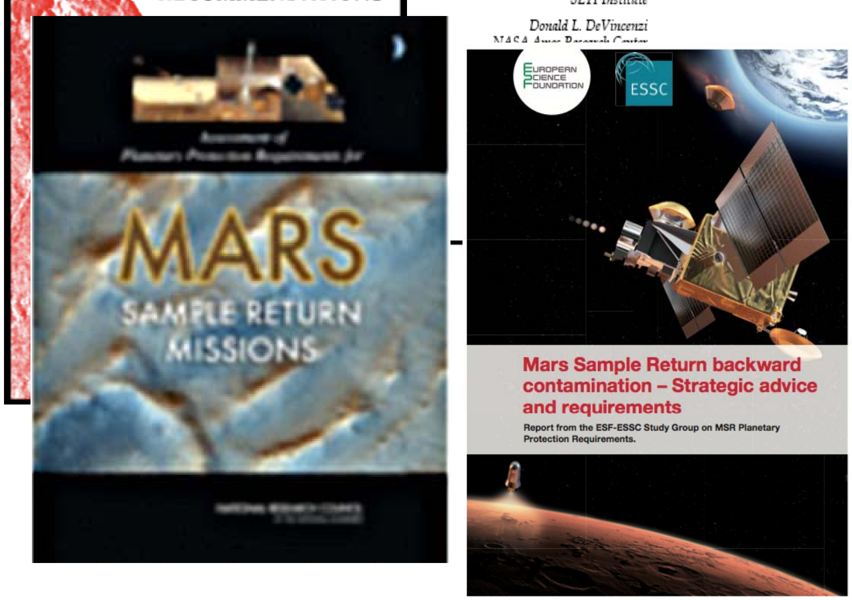
## Planetary protection is mentioned in the report:

**Finding 10-1:** In order for a cache to be returnable, it must comply with NASA Planetary Protection requirements in order for future planners to request permission to return it, should they choose to do so.

# Returning Martian Samples to Earth






- Previous requirements developed over a decade of MSR preparation and adopted by COSPAR
- ESA and NASA are continuing a program of requirements refinement, based on advice from the COSPAR members US-NRC and EU-ESF.
- Key recommendations:

NRC: "…samples returned from Mars by spacecraft should be contained and treated as though potentially hazardous until proven otherwise."

ESF: "The probability that a single unsterilised [martian] particle of 0,01 µm diameter or greater is released into the Earth's environment shall be less than $10^{-6}$."

# Relevant NASA Requirements for Mars Sample Return



5.3.3 PP Category V. The Earth return portion of a Mars Sample Return mission is classified as "Restricted Earth return," with all outbound portions required to meet associated requirements. Guidelines for sample return missions are as follows:

5.3.3.1 Samples returned from Mars by spacecraft shall be contained and treated as though potentially hazardous until demonstrated otherwise.

5.3.3.2 Unless specifically exempted, the outbound leg of the mission shall meet PP Category IVb requirements. This provision is intended to avoid "false positive" indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned.

5.3.3.7 For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample.

5.3.3.11 An independent science and technical advisory committee shall be constituted with oversight responsibilities for materials returned by a Mars sample return mission.

# What Does ‘Potentially Hazardous’ Imply?



- Hazards must be either destroyed or contained
  - ➢ Contain Mars samples or sterilize them, to ensure safety of Earth
- Must have sufficient confidence on containment
  - ➢ Requirements involve the probability of releasing a single particle of unsterilized Mars material into the Earth environment
- Must have approved protocols for containment and testing
  - ➢ Review and update Draft Test Protocol using best available advice
  - ➢ Requirements on flight system contamination flow back from life detection protocols
- Technical requirements flow from the hazard assessment
  - – Impact on design and operation
  - – Impact on flight and ground system (C&C)
  - – Impact on hardware and software
  - – Impact on qualification and acceptance margins

# MSR Campaign-Level Planetary Protection Requirements



- Campaign level categorization and individual mission-phase requirements:
  - All flight elements of a Mars Sample Return effort that contact or contain materials or hardware that have been exposed to the martian environment to be returned to Earth are designated "Planetary Protection Category V, Restricted Earth Return"
  - Landed elements must adhere to requirements equivalent to Planetary Protection Category IVb Mars missions, or Planetary Protection Category IVc should the landed element be intended to access a 'special region'
  - Orbital elements, including hardware launched from Mars, must meet requirements equivalent to Planetary Protection Category III Mars mission

# Category IVb Requirements for Mars (paraphrased)



Category IVb. For lander systems intended to investigate extant martian life, all of the requirements of Category IVa apply. In addition, one of the following conditions shall be met:

1. The total bioburden of the surface system is ≤ 30 bacterial spores on exposed internal and external surfaces, or at a contamination level driven by the nature and sensitivity of the particular life-detection investigations.

2. The average bioburden of the subsystems that are involved in the acquisition, delivery, and analysis of samples used for life-detection investigations is either:

(a) ≤ 0.03 bacterial spores/m2, or

(b) **at a contamination level driven by the nature and sensitivity of the particular life-detection investigations,**

**and recontamination prevention of these subsystems and the samples to be analyzed is in place until the end of the life-detection investigations.**

# Refining Category IVb Requirements



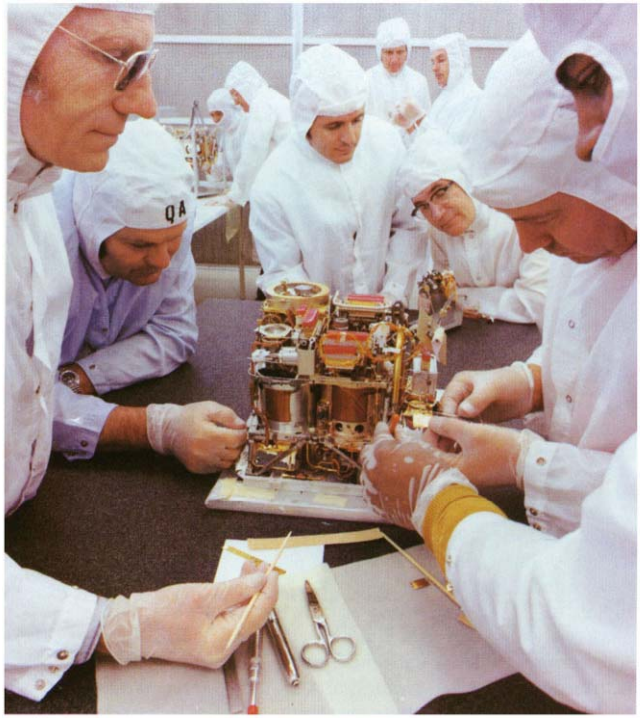
What does the requirement "**driven by the nature and sensitivity of the particular life-detection experiments**" actually imply?

- Life detection/biohazard experiments performed on Mars material returned to Earth will involve the best state-of-the-art instrumentation and capabilities available at the time
- Confidence in the conclusions of the protocol must be high, to ensure effective oversight and risk assessment; refine requirements for future Mars missions, including human missions; and potentially permit release of unsterilized samples from containment
- Type of measurements and detection sensitivity will drive contamination limits on all elements of an MSR campaign, including initial sample caching missions

# Cleaning Spacecraft Right: Viking



## The Inquisition approach...

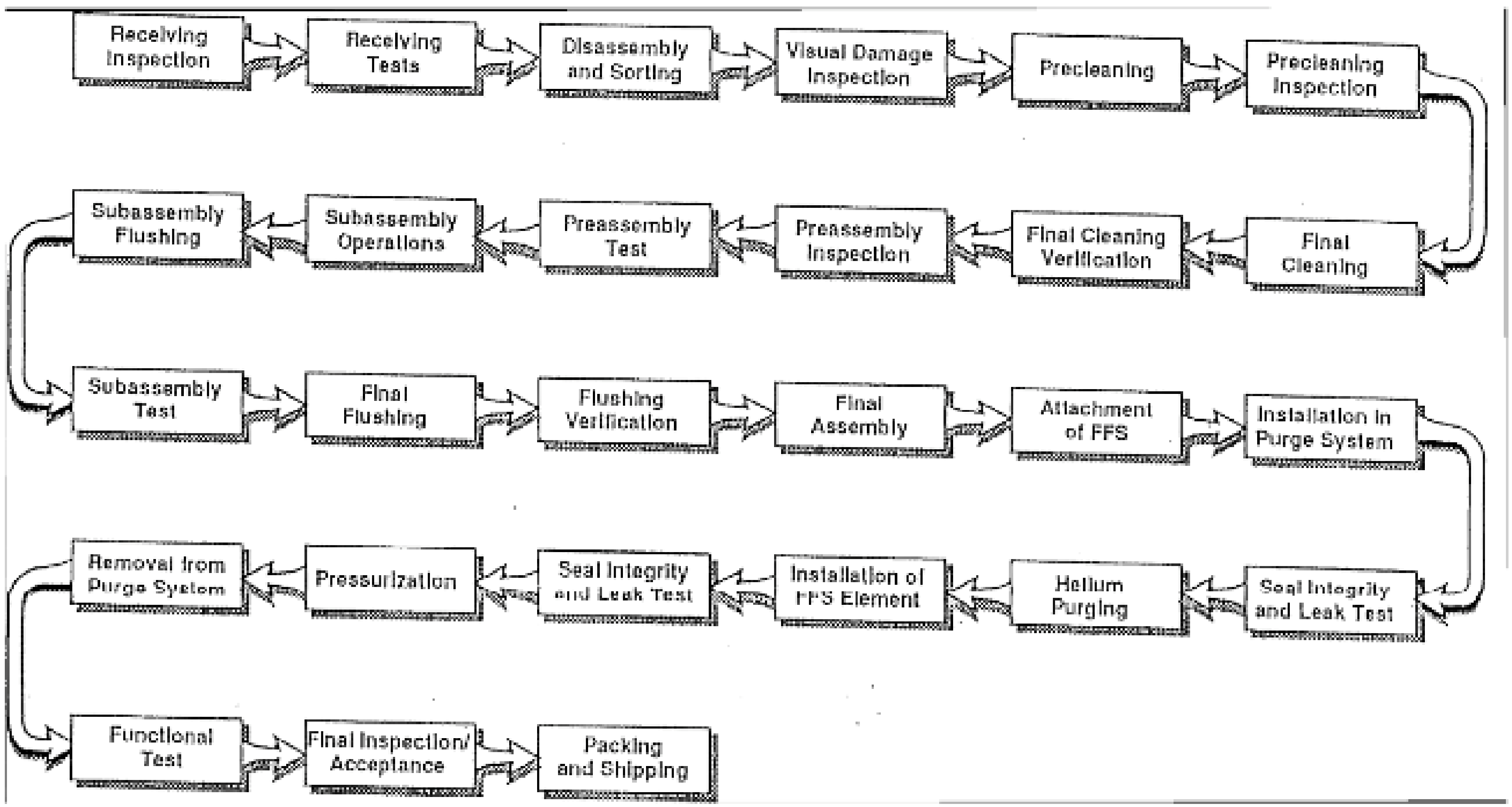


Multi-step biological burden reduction ensured adequate contamination prevention for both Mars and the samples being analyzed.

Plus subsystem cleaning and recontamination prevention.

# Viking MS Cleaning Protocol

Planetary Protection




Subsystem cleaning and recontamination prevention...

# MSL Heritage Considerations



- Forward and backward contamination implications
- – Presence of an RTG invokes landing site constraints similar to MSL – no ice within reach of a crashed spacecraft, for a 3?-sigma error ellipse reachable by any failure after parachute opening
- – Need to assess potential for contamination from rover to be delivered to samples/sampling hardware: mitigate by overpressured recontamination prevention (a la Viking)
- – Critical input to determining allowable levels of organic contamination will be early results from SAM and the detailed analysis of the MSL Contamination Control Tiger Team
- – The recognition, from PHX and MSL, that reactive compounds are present in Mars regolith, makes interpretation of organic measurements more challenging – as recent reinterpretation of Viking results also demonstrates

# Evolution of Requirements - Bioburden



Campaign level requirement according to Planetary Protection Category V, restricted Earth return:

The subsystems of one or several missions which are involved in the acquisition, delivery and storage, and analysis of samples used for life detection must be sterilized or cleaned to levels of bioburden reduction driven by the nature and sensitivity of the particular life-detection experiments driven by the life detection and biohazard assessment protocol, and a method of preventing recontamination of the sterilized subsystems and the contamination of the material to be analyzed is in place.

# Draft Test Protocol Framework

**Table 4: General Principles Guiding the Search for Life:**

- Begin with a broad survey of a portion of different sample types for more general features suggestive of life, then turn to a higher resolution examination of sites with suggestive features for more complete characterization
- Emphasize structural signatures of life and other inhomogeneities that can be easily detected as a first order task
- Emphasize less destructive methods in the early stages of investigation, since they can guide the use of more definitive but destructive methods
- ~~Start with samples which are the least likely to contain life (e.g., surface fines); if negative, use these as blanks and controls for spiking experiments~~
- Recognition of life will require the coincidence of multiple independent signatures
- Inactive or "past" life will be treated as potentially active life
- Generalize a carbon-centered methodology to other chemical species
- Use an iterative approach for the Life Detection protocol
- Invest significant time to the design of controls and blanks, as early in protocol development as possible

NASA/CP—2002–211842

A DRAFT TEST PROTOCOL
FOR DETECTING POSSIBLE BIOHAZARDS IN
MARTIAN SAMPLES RETURNED TO EARTH

# Returned Sample Handling Overview

SAMPLE CANISTER 'HEALTH CHECKS'
(Earth Entry OK, Landed Safely, etc.)

TO SRF

OPENING OF CANISTER
PRELIMINARY EVALUATION (Samples, Gases, etc.)
- Initial Sub-sample Allocations
- Assessment of Preservation Requirements

"PHYSICAL/CHEMICAL" PROCESSING

FURTHER ANALYTICAL TESTS
- Confirm Representative Sample
- Support Further Testing

SAMPLE
PRESERVATION
(Pristine Curation)

LATER ANALYSES
"Sterilization" and/or
"Release"? TBD

"LIFE DETECTION"
("Informed") TESTING

CARBON CHEMISTRY?
MORPHOLOGY?
REDOX COUPLES/
METABOLIC POSSIBILITIES?
TERRESTRIAL BACKGROUND?
HERITAGE?
ETC.

NEED TO KNOW?!
WHAT ARE THE CONSEQUENCES?
- No Life or Hazard Detected
- False Positives (Earth life forms)
- Life on Mars

All of these processes and measurements are relevant to both 'science' and 'planetary protection' – the major difference is what each *does* with the information.

(There are a small number of activities specific for detecting biohazards that may need to be done, but this is beyond the scope here.)

# PROPERTIES OF LIVING SYSTEMS (J. Farmer)

- **Order** - The structures and subsystems of living systems are highly ordered.
- **Replication** (reproduction) - Organisms replicate themselves through various methods of asexual, or sexual reproduction.
- **Growth and development** – In higher organisms there is a pattern of development controlled by regulatory genes.
- **Energy utilization** - Life utilizes a broad array of processes to extract energy from its environment.
- **Response to the environment** - Organisms interact with and respond to their environment.
- **Evolutionary adaptation** - Life adapts to environmental changes over time through mechanisms of Darwinian evolution.

Necessary versus sufficient…all are necessary, but none sufficient.

# Refining the Life Detection Protocol



The protocol addresses life based on carbon chemistry that happens at Mars/Earth near-subsurface temperatures and pressures, on human-detectable timescales.

Information addressing the properties of life as defined above might be found by measuring:
1) Structure and morphology of samples, at macro and micro scales
2) Chemical composition and heterogeneity of samples
3) Environmental and thermodynamic context of samples and interesting features within

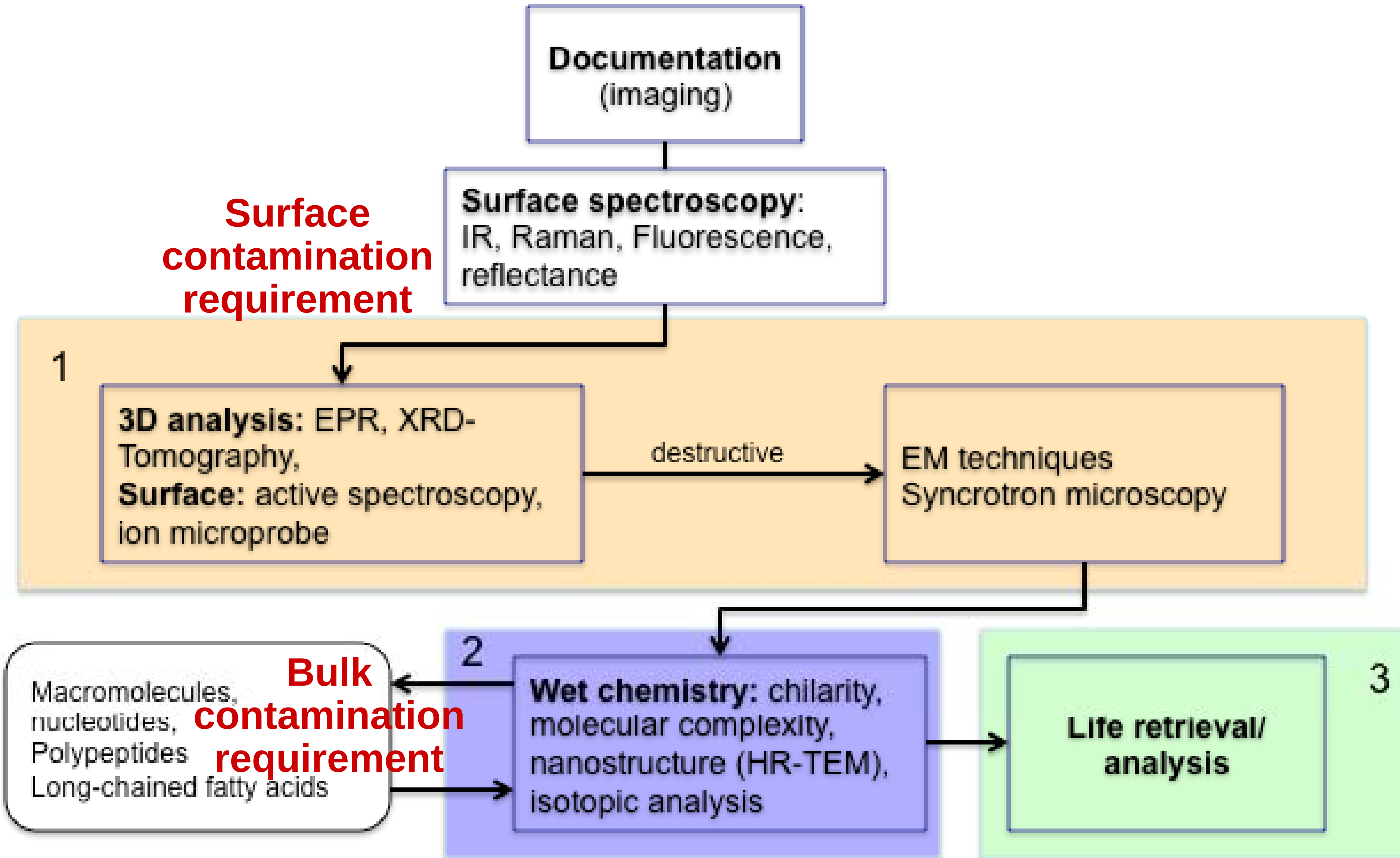
Testing competing 'null' hypotheses is an effective strategy to address both scientific and planetary protection interests. Hypotheses are:
1) There is no life in the samples.
2) There is Mars life in the samples.

***Data*** will be collected; these data may be equally relevant to 'science' and 'planetary protection.' ***Interpretation*** of collected data will guide policy decisions regarding sample safety and subsequent handling, as well as inform scientific research.

Characterization of measurements as 'strong biosignatures,' 'possible biosignatures,' 'indicators of abiotic processes,' or 'indicators of Earth contamination' could be useful

A decision analysis strategy based on Bayesian statistics could be used to direct sequences of investigations to increase confidence in conclusions as input to policy

# Example Scheme



# MSR Campaign-Level Life Detection Considerations



- Campaign level requirements:
  - all items returned from Mars shall be treated as potentially hazardous until demonstrated otherwise: *avoid adherent dust from atmosphere*
  - release of unsterilized martian material shall be prohibited: <10nm particle at $<1\times10^{-6}$ probability: *ESF study input to COSPAR*
  - subsystems sterilized/cleaned to levels driven by the nature and sensitivity of life-detection experiments and the planetary protection test protocol: *Viking/ExoMars organic cleanliness with IVb subsystem bioburden control, and recontamination prevention through return*
  - life-detection measurements dictate limits on contamination/recontamination of the samples: *assume instrumentation at least as sensitive as today*
  - need methods for preventing recontamination of the sterilized and cleaned subsystems and returned material: *technology development*
  - presence of a long-term heat source (RTG) would impose additional landing site restrictions to prevent both nominal and off-nominal spacecraft-induced "special regions":

# Current Capabilities Will Improve...



- Instrumentation used on returned Mars samples will be at least as sensitive as today's instrumentation
- Detection of organic material on surfaces can attain femtomolar/attomolar sensitivity over micron-scale spots (e.g., LDMS; other desorption techniques)
- Detection of organic material in bulk samples can attain parts-per-billion sensitivity (ng/g)
- Capabilities to verify pre-launch organic/biological cleanliness may constrain requirements in practice
- Provisional guidance can be derived from past and current missions, but additional work is necessary to assess current capabilities and extrapolate future needs

# Clean Sample Handling...